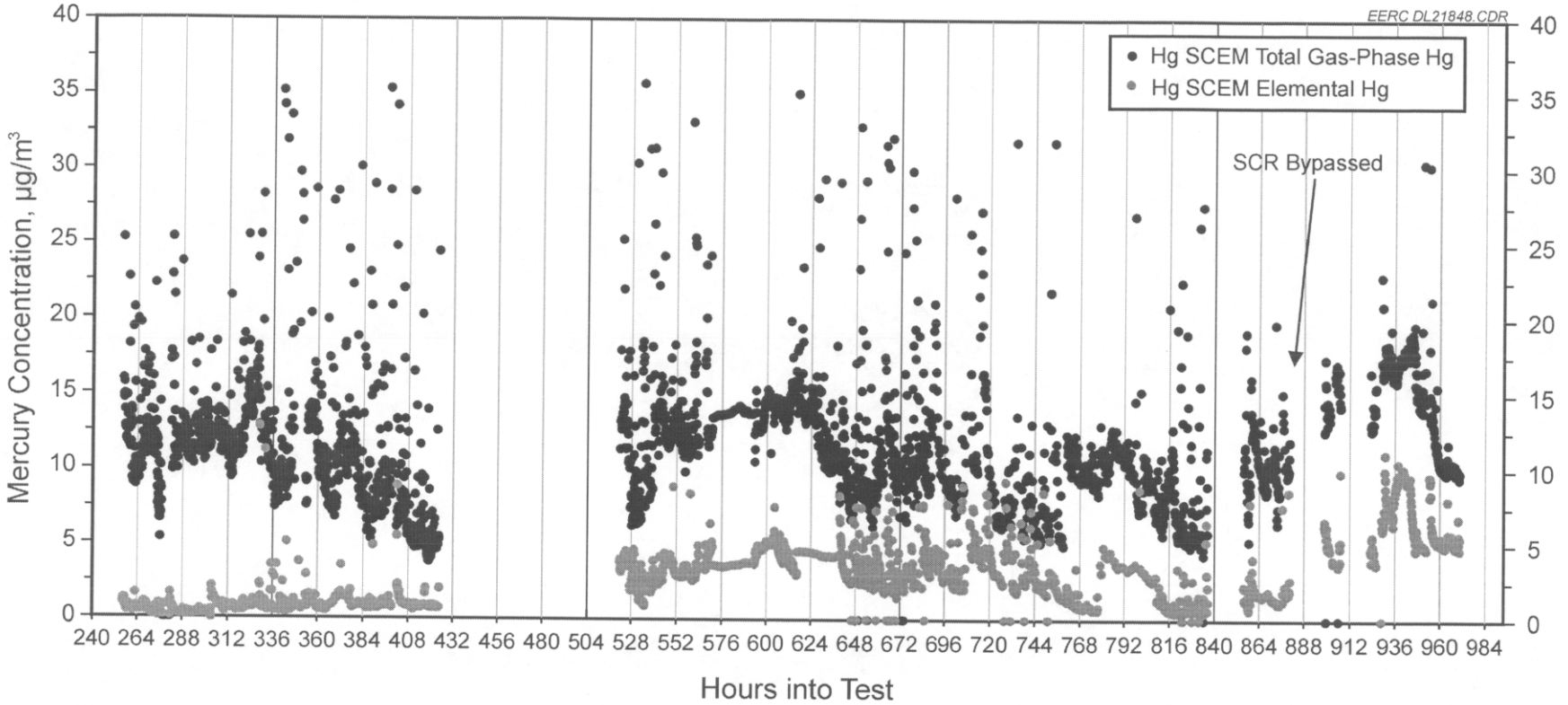

Figure 3-5
Hg SCEM Results for Site S4

Table 3-4
Statistical Variation of the Mercury with and Without the SCR in Service Based on the Hg SCEM Data for Site S4

Mercury	Operation	Average, $\mu g/m^3$	Std. Dev., $\mu g/m^3$	Upper 90% CI, $\mu g/m^3$	Lower 90% CI, $\mu g/m^3$
Hg(total)	With SCR	11.5	4.5	18.5	4.1
Hg^0	With SCR	2.3	1.7	5.1	0.0
Hg(total)	SCR bypassed	14.6	3.6	20.5	8.7
Hg^0	SCR bypassed	6.3	1.9	9.4	3.2

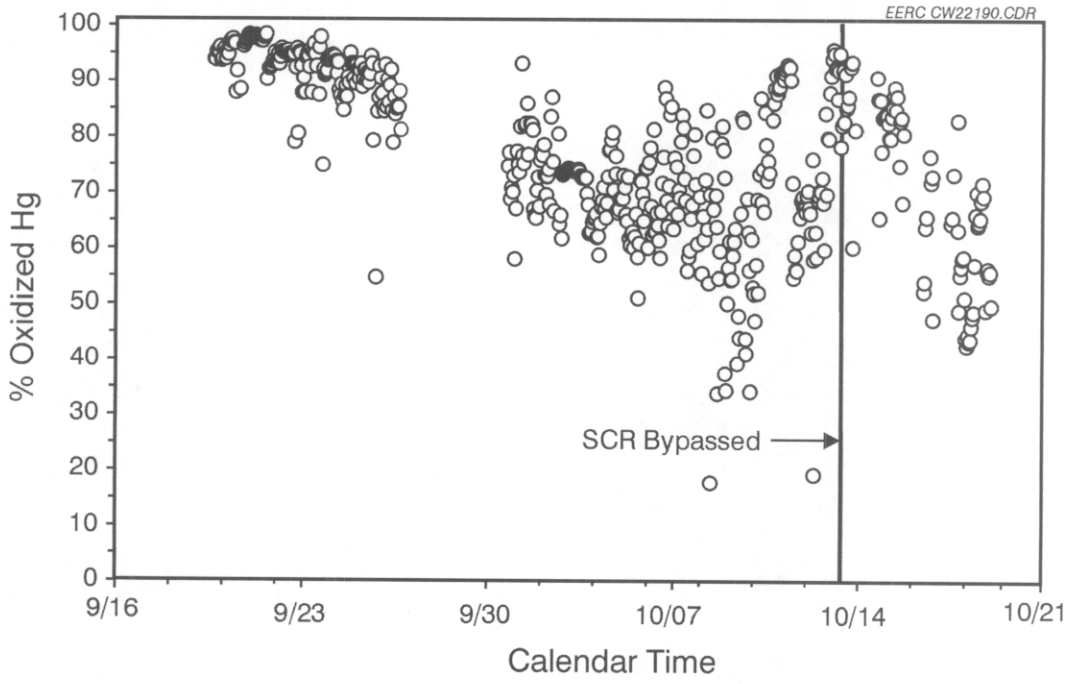

Figure 3-6
Average Hg^{2+} as Measured by Hg SCEMs (Total Hg–Hg^0) for Site S4

3.4.3 Coal Analysis Results

As stated in Section 3.1, Site S4 burns a medium-sulfur Kentucky bituminous coal in a cyclone boiler. The analysis of the coal fired is shown in Table 3-5. The coal analysis shows that the coal was relatively constant in 2002. However, in 2001 at Site S4, the chloride content in the coal increased from an average of 360 ppm with SCR in service to 1160 with SCR bypassed. Therefore, it is possible that some of the differences in Hg oxidation across the SCR catalyst between the 2001 and 2002 testing may be due to differences in the coal.

Table 3-5
Coal Analysis for Site S4[a]

Date	9/11/2002	9/12/2002	9/13/2002	10/16/2002	10/17/2002
Mercury ppm (dry)	0.17	0.16	0.15	0.19	0.14
Chlorine ppm (dry)	269	228	241	270	295
Proximate Analysis					
Moisture, wt%	12.3	12.6	11.8	11.3	11.2
Volatile Matter, wt%	35.1	35.3	35.5	35.5	35.5
Fixed Carbon, wt%	44.1	43.4	43.8	45.0	45.0
Ash, wt%	8.5	8.7	8.8	8.2	8.4
Ultimate Analysis					
Hydrogen, wt%	6.8	6.9	6.8	5.6	5.5
Carbon, wt%	65.7	66.3	66.5	74.6	77.2
Nitrogen, wt%	1.3	1.3	1.3	1.6	1.9
Sulfur, wt%	2.8	2.7	2.8	2.8	2.7
Oxygen, wt%	14.1	13.8	13.1	7.0	4.9
Heating Value, Btu/lb	11,597	11,468	11,409	11,852	11,848
F_d,[b] dscf/10^6 Btu	10,397	10,664	10,733	11,217	11,592

[a] Except where stated, all results are on an as-received basis.
[b] As defined in EPA Method 19.

3.4.4 Mercury Collected by the Venturi Scrubber

As shown in Table 3-6, there appears to be less Hg captured by the venturi scrubber when the SCR is bypassed, as expected.

Table 3-6
Partitioning of Mercury in Material Collected from Venturi Scrubber

Date	Hg in FGD Material, μg/g	Solids, %
9/11/2002	0.14	15.6
9/12/2002	0.11	16.2
9/12/2002	0.10	14.3
9/13/2002	0.08	15.2
10/16/2002	0.03	12.4
10/17/2002	0.04	12.5

3.4.5 NH_3 Slip and SO_3 Flue Gas Results for Site S4

The results for NH_3 slip and SO_3 concentrations for each of the tests conditions are shown in Table 3-7. The NH_3 slip concentrations are low (<2 ppm), indicating a well-performing SCR. This is also shown by 87% NO_x removal efficiency. Within the statistical variation of the measured values, the SO_3 concentration at the SCR outlet and inlet locations were the same. At Site S4, it does not appear SCR increased the conversion of SO_2 to SO_3. Results were similar to those obtained from testing conducted in 2001.

Table 3-7
S4 Flue Gas, NH_3 Slip, and SO_3 Results for Site S4[a]

Test Condition	Date	NH_3 Slip SCR Outlet, ppm	SO_3 SCR Inlet, ppm	SO_3 SCR Outlet, ppm
SCR On-Line	9/11/2002	0.04	10.9	14.4
SCR On-Line	9/11/2002	0.18	13.4	10.3
SCR On-Line	9/11/2002	1.33	—	—

[a] All results are reported on a dry, 3% O_2 basis.

3.5 Mercury Mass Balance

The Hg balance is determined by comparing the concentration of Hg in sources entering the plant to the concentration of Hg in the sources emitted from the plant. Site S4 has a venturi scrubber. Without information regarding scrubber flow, slurry, and blowdown rates, it is not possible to do a mass balance around the FGD. The average F_d factors for Site S4 are shown in Table 3-8. A Hg balance comparing the measured Hg in the flue gas at the air heater outlet location compared to the Hg generated by the coal is 86% with SCR and 99% for the test conducted with SCR bypassed.

Table 3-8
Average Mercury Emission Factors for Site S4

	Coal, lb/10^{12} Btu	Air Preheater Outlet, lb/10^{12} Btu	Stack, lb/10^{12} Btu	Overall Hg Removal, %
With SCR in Service	10.8	9.3	0.9	92
With SCR Bypassed	10.8	10.5	6.9	45

3.6 General Observations from S4

- There was increased Hg oxidation across the SCR catalyst as the percentage of Hg^{2+} in the flue gas increased from 32% at the SCR inlet to 62% at the outlet. At the air preheater outlet location, the percentage was 96%.
- Comparing the 2002 results with those obtained in 2001 indicated that the percentage of Hg oxidation that occurred across the SCR unit in 2001 decreased. It is unknown if this is due to a catalyst-aging effect or changes in the coal composition, in particular the chloride concentration. Although there was a decrease in Hg oxidation across the catalyst, the overall Hg removal at Site S4 did not change: 91% in 2002 compared to 90% in 2001.
- Comparing the Hg speciation results (at the air preheater outlet location) with and without the SCR in service showed that the presence of the SCR unit resulted in increased Hg oxidation from 57% without SCR to 96% with SCR. As a result, the overall Hg removal across the venturi scrubber increased from 44% to 91%, when the SCR was in service.
- Although there was an increase in Hg^0 across the venturi scrubber, it was very small: 0.5 to 0.8 $\mu g/Nm^3$. This is within the variability of the data.
- There was substantial variability in Hg and Hg speciation as measured using the Hg SCEMs.
- Based on the measurement, it appears that the SCR unit did not result in SO_2 to SO_3 oxidation (note: these results are similar to those generated in 2001).

4
SITE S5

Site S5 was selected for inclusion in the 2002 SCR testing program to provide additional data on the effect of SCR on speciated Hg emissions for an eastern bituminous coal with a wet FGD, in particular how it impacts the Hg removal across a wet FGD. Two "sister" units were tested at Site S5. They are essentially the same design except one does not have an SCR unit.

4.1 Site Description and Configuration

Site S5 fires a West Virginia high-sulfur bituminous coal. The unit with SCR has a plate configuration catalyst manufactured by Halder-Topsoe. The SCR unit had a space velocity of 3700 hr^{-1} and had operated for approximately 3 months prior to testing. Both the units tested operated ESPs for particulate control and wet FGDs to reduce SO_2 emissions. Information about the configuration of the two units is presented below:

- Fuel type: West Virginia bituminous coal
- Boiler capacity: 684 MW
- Boiler type: wall-fired pc
- NO_x control: SCR on one unit; low-NO_x burners on both units
- Particulate control: ESP
- SO_2 control: magnesium-enhanced lime FGD

Schematics of the two units at Site S5, including sampling locations, are shown in Figures 4-1 and 4-2. As shown in the figures, the ESP configuration was slightly different. The unit without SCR had a second ESP in series.

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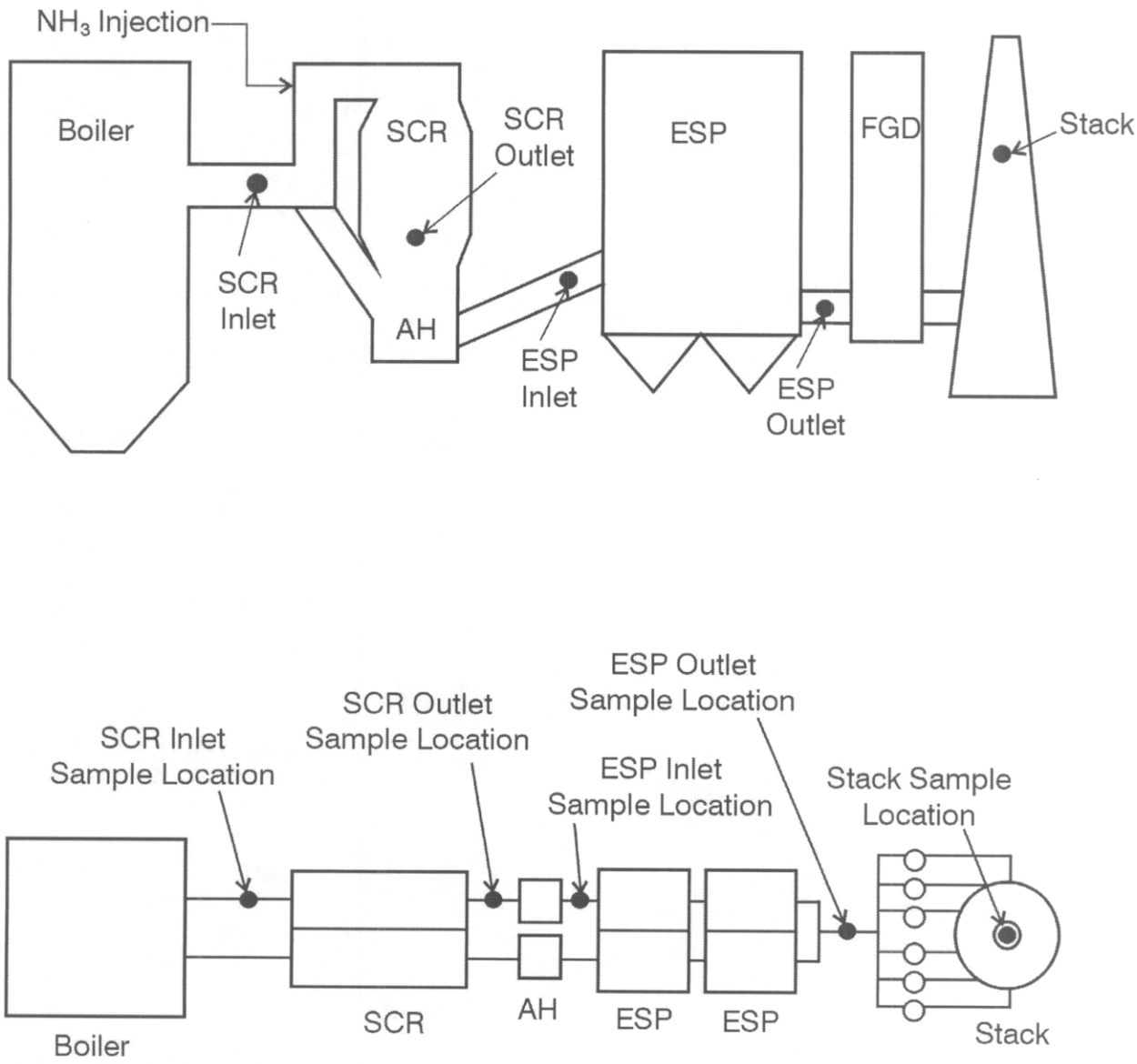

Figure 4-1
Schematic of Site S5 Showing Sample Locations for the Unit with the SCR from a Vertical and Horizontal Perspective

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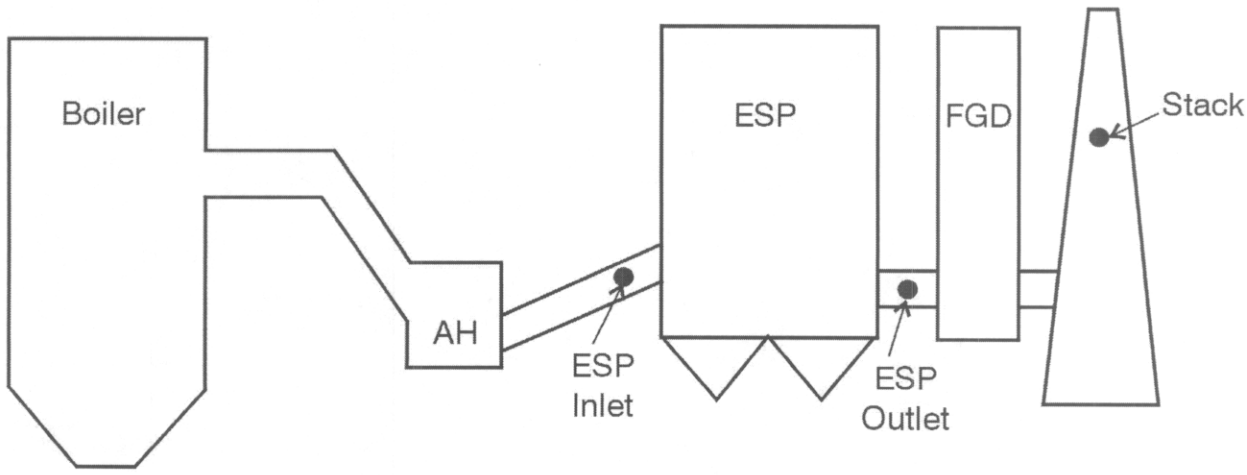

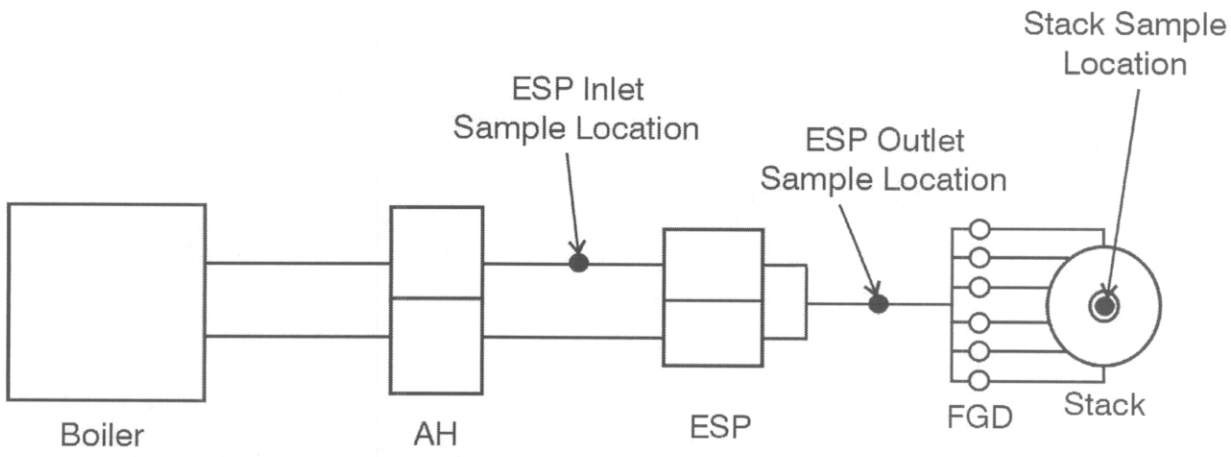

Figure 4-2
Schematic of Site S5 Showing Sample Locations for the Unit with No SCR from a Vertical and Horizontal Perspective

4.2 Sampling Approach

4.2.1 Flue Gas Sample Streams

The flue gas Hg speciation was measured using the OH method at five locations for the unit with SCR and three locations for the unit without SCR. A test matrix, which identifies the location of flue gas measurements, is provided in Table 4-1. Where practical, OH measurements were conducted simultaneously across the various control devices in an effort to quantify the effect

Table 4-1
Sampling Test Matrix for Site S5

Date		SCR In	SCR Out	ESP In	ESP Out	Stack	AH In	ESP In	SCR Out	SCR Out
Begin	End	OH	OH	OH	OH	OH	SO_3	SO_3	SO_3	NH_3
With SCR										
07/26/02	07/28/02				3					
08/15/02	08/23/02	3	5	3	5	2		3	3	3
Without SCR										
07/26/02	07/28/02				3					
08/13/02	08/23/02			3	4	3	2	2		

each had on Hg concentration and speciation. In addition to Hg, flue gas samples were collected to measure the total particulate loading and SO_3 concentrations. Additionally, NH_3 slip samples were collected from the unit with SCR to evaluate performance.

Longer-term Hg monitoring was conducted using Hg SCEMs (PSA) located at the ESP outlet (same as the FGD inlet) locations for both test units. These data provided semicontinuous Hg^0 and total gas-phase Hg concentrations for approximately 3 weeks.

4.2.2 Other Sample Streams

Samples of coal and ESP hopper ash were collected from both test units in an effort to obtain representative operational data related to Hg speciation. These samples were analyzed for Hg and, along with the flue gas emission data, were used to qualitatively evaluate the fate of Hg throughout the units. Coal samples were collected daily throughout the test period from the coal feeder of both units. ESP hopper ash samples were collected from the first fields of the ESPs. Ash samples for the unit with SCR were obtained from both Sides A and B of the ESP; however, the sample collected from the unit without SCR was obtained from only Side A of the ESP. Plant personnel did not collect samples from the FGD system.

4.3 Process Operating Conditions

Plant operational data are presented in Figures 4-3 and 4-4 for the two test units. These figures summarize flue gas characteristics during the test program. Additionally, monthlong Hg SCEM data are included in these plots for comparison with plant operational data. Hg SCEM data will be discussed later in this report. In general, for the unit with SCR, plant load remained greater than 80% of full capacity, with the exception of a 35-hour period ~400 hours into the test and a few short reductions at night. These reduced load conditions did not have a significant impact on

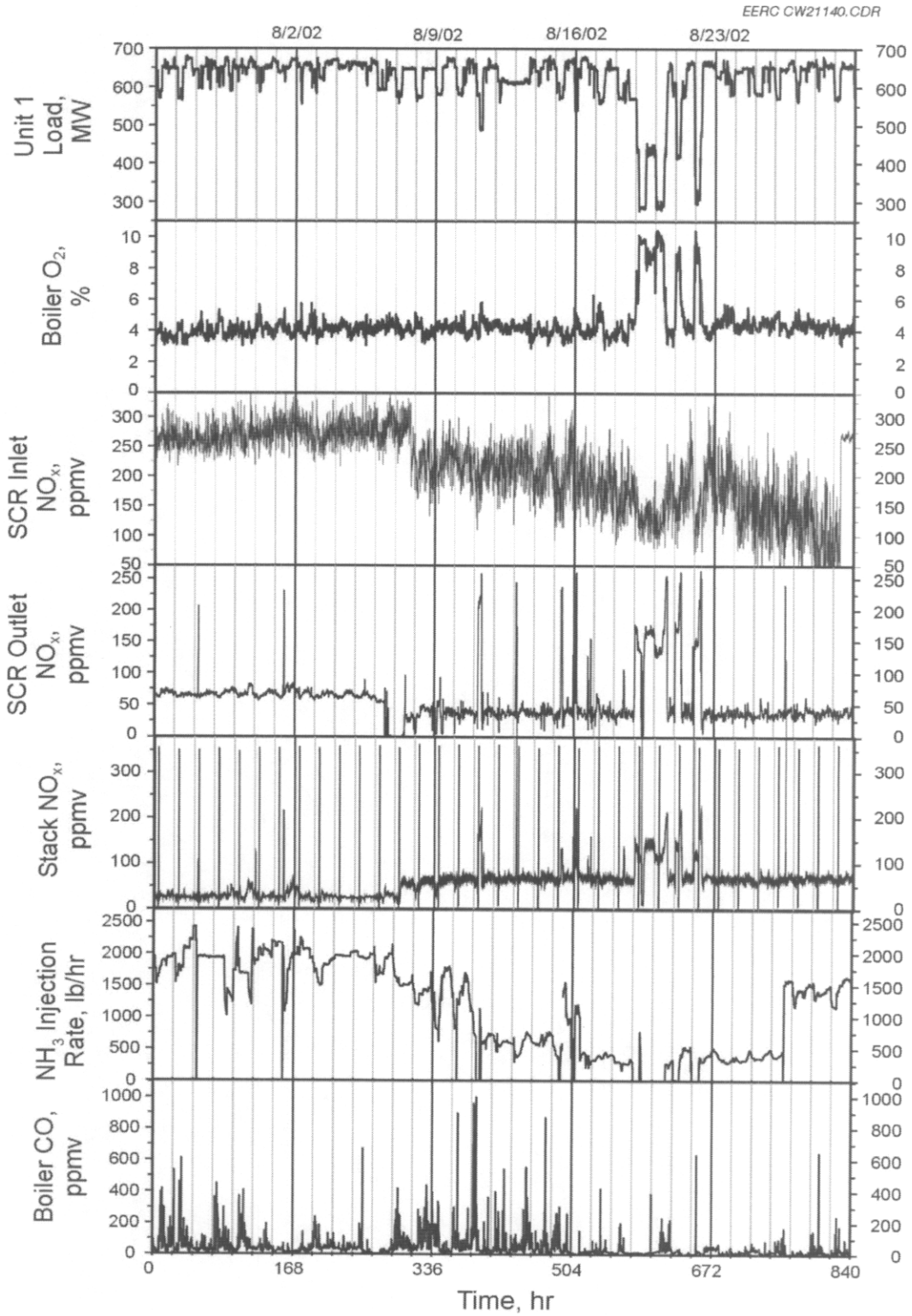

Figure 4-3
Plant Operation Data for Site S5 for the Unit with the SCR

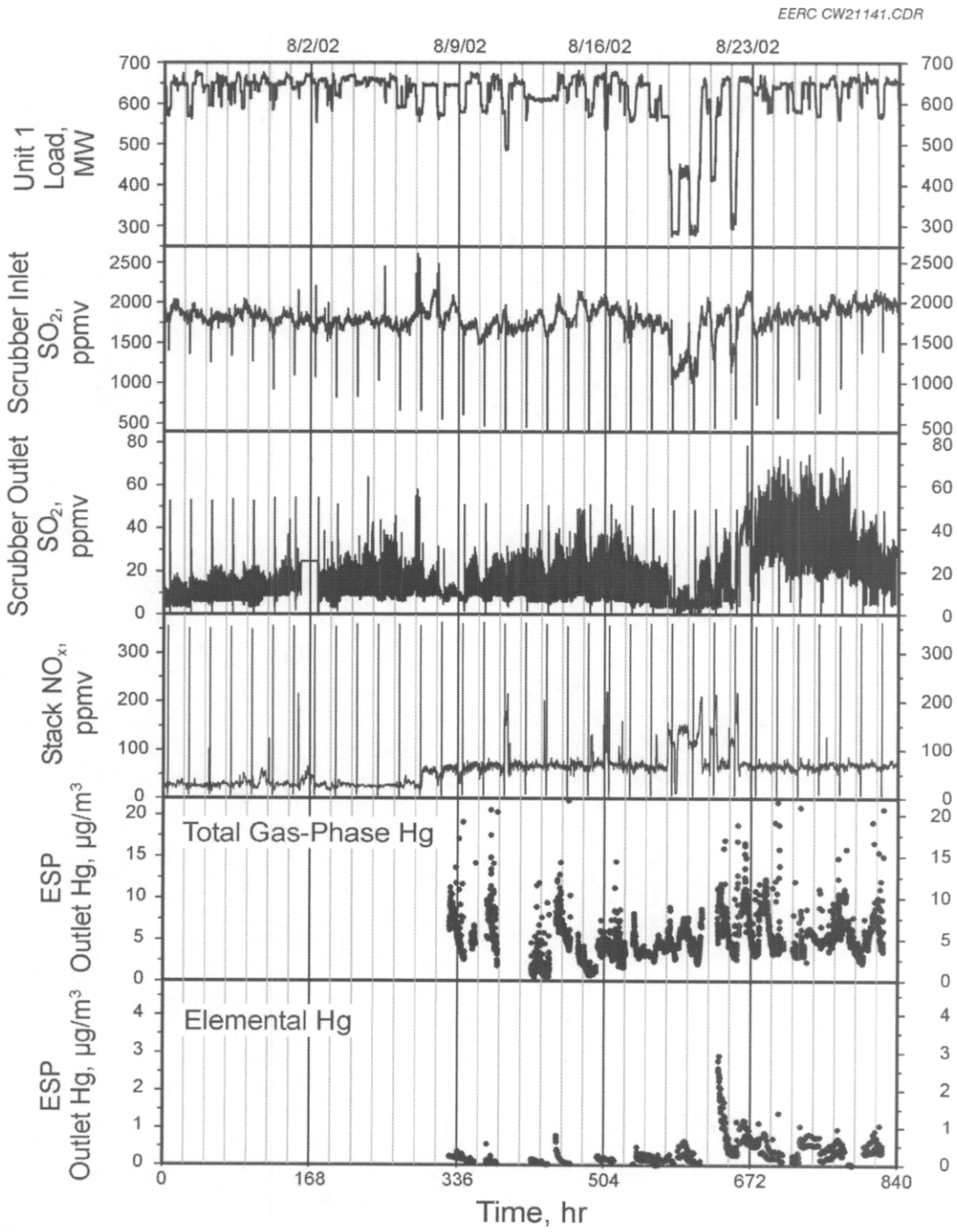

Figure 4-3 (continued)
Plant Operation Data for Site S5 for the Unit with the SCR

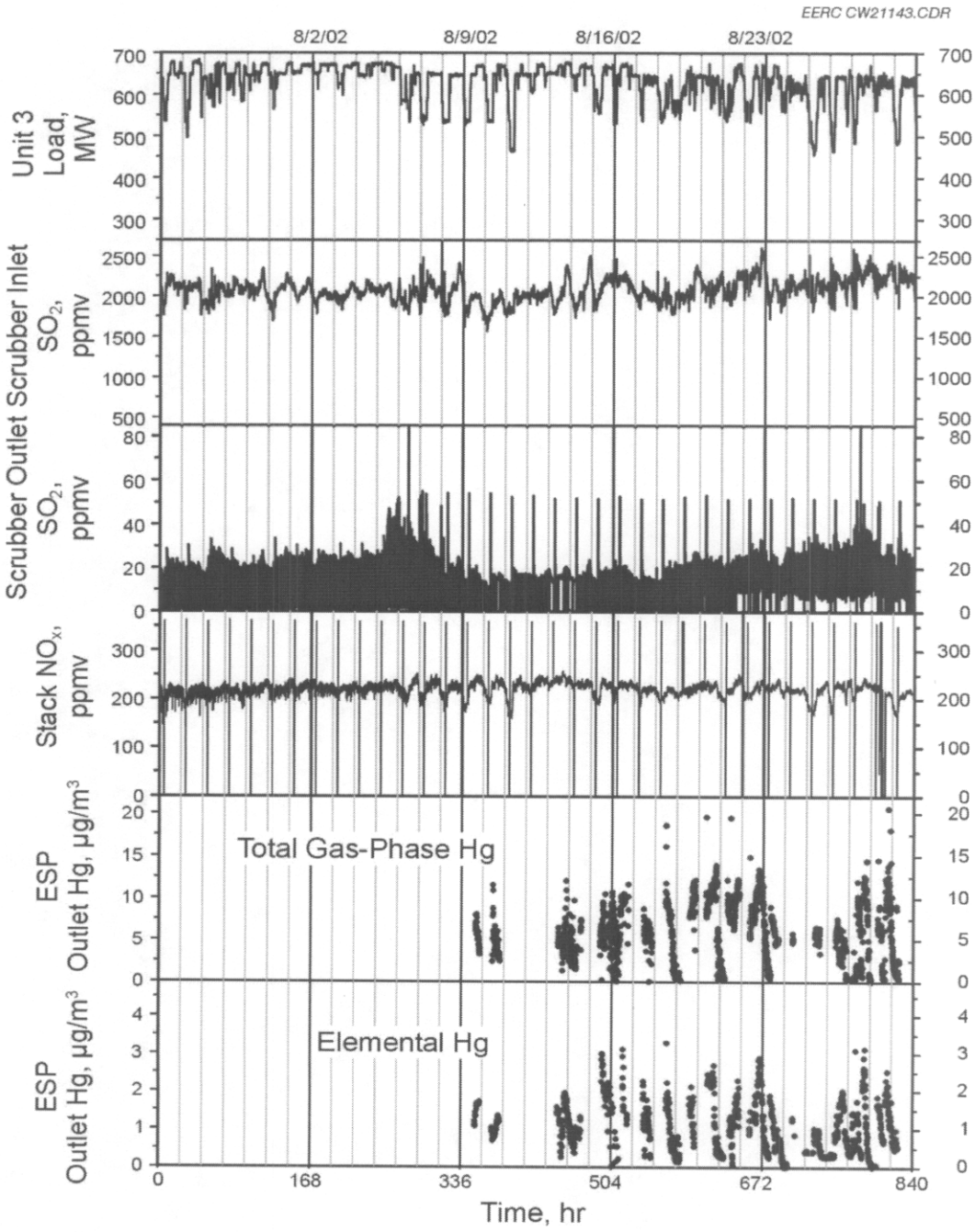

Figure 4-4
Plant Operation Data for Site S5 for the Unit with No SCR

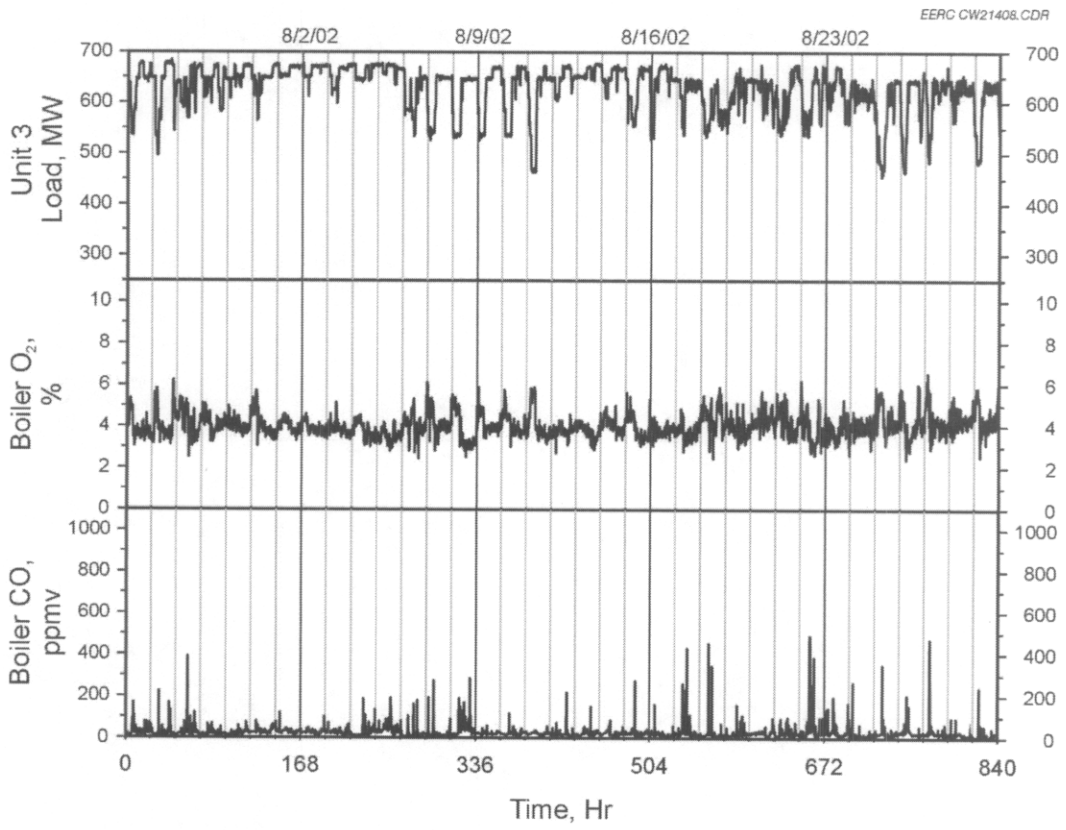

Figure 4-4 (continued)
Plant Operation Data for Site S5 for the Unit with No SCR

Hg as measured by the Hg SCEMs or OH method. The unit without SCR did not experience any significant load reductions below 80% of full capacity during the test program.

For the unit with SCR, the inlet NO_x concentration reduced noticeably beginning around 300 hours into the test from approximately 260 to less than 200 ppmv. In response to that reduction, the NH_3 injection rate was reduced to maintain an SCR outlet NO_x concentration of approximately 50 ppm. Also, note at about 750 hours into the test, there is a substantial increase in the NH_3 injection rate that corresponds to a spike in the SCR inlet NO_x concentration. Overall, an 80% reduction in NO_x was measured across the SCR unit.

Boiler CO for both units spiked intermittently from less than 50 to 400–800 ppm. However, there does not appear to be any correlation between elevated CO concentration and shifts in Hg concentration from either OH or Hg SCEM results.

A summary of auxiliary flue gas data, including percent O_2 and percent CO_2 for each sample location, is provided in Table 4-2. The complete data set is located in Appendix C, Table C-3. In general, the percent moisture, CO_2, and O_2 were very consistent from day to day. However, there was air leakage across the SCR unit, air preheater, and wet FGD system that resulted in the O_2 increasing from 4% at the boiler outlet to 7.8% at the stack. Dust-loading measurements collected at the ESP inlet and outlet location reflect a particulate removal efficiency of approximately 95% for both units based on an average of inlet and outlet dust loadings. Based on

Table 4-2
Auxiliary Flue Gas Data for Site S5[a]

Date	Unit with SCR				Unit Without SCR			
	Moisture, %	Dust, gr/dscf	CO_2, %	O_2, %	Moisture, %	Dust, gr/dscf	CO_2, %	O_2, %
SCR Inlet	10.7	3.5652	14.3	5.0				
SCR Outlet	9.1	3.4083	13.8	5.7				
ESP Inlet	8.9	1.6848	13.1	6.5	8.6	0.8287	13.6	6.1
ESP Outlet	8.7	0.0751	12.9	6.7	9.0	0.0453	12.9	6.7
Stack	13.1	0.0073	11.9	7.8	13.5	0.0063	12.7	7.0

[a] Dust loadings were collected as part of the OH method using EPA Method 17 and, therefore, are not for compliance purposes.

discussions with plant personnel, the ESPs at S5 are not extremely efficient, which is reflected by these values.

4.4 Sampling Results

4.4.1 OH Flue Gas Mercury Results

The average Hg results from gas sampling are summarized in Table 4-3. The complete data sets are presented in Appendix B (Tables B-5 and B-6). Figure 4-5 shows a comparison of the data for the unit with the SCR and the unit without an SCR. As shown in Table 4-3, there is significant oxidation of Hg occurring across the SCR catalyst, from 43% Hg^{2+} to 76% Hg^{2+}. The percentage of Hg^{2+} is further increased to 95% at the inlet to the ESP. It should be noted that the apparent increase in Hg^0 across the ESP for the unit with ESP is most likely due to reactivity with the fly ash across the filter of the OH method.

Comparing the ESP inlet Hg speciation results for the two units indicates that the percentage of Hg^{2+} was 80% without SCR and 95% with SCR. However, as shown by the error bars in Figure 4-5, the OH data at this location were highly variable. If the ESP outlet data are used, the difference is from 63% to 94%. This is more in line with the overall Hg removal of 91% with SCR as compared to only 51% for the unit without SCR.

One objective for testing Site S5 was to evaluate the combined effect of an SCR unit and wet FGD system on Hg speciation and removal. For the unit without SCR, the measured Hg^{2+} was 63% of the total Hg. However the Hg removal efficiency of the wet FGD system was only 51%. This is a result of the Hg^0 increasing from 4.7 to 6.1 $\mu g/Nm^3$ across the wet FGD system. With SCR, Hg^{2+} is 94% of the total Hg, and the total Hg removal by the wet FGD system is 91%. There is still an increase in Hg^0 (0.7 to 1.0 $\mu g/Nm^3$) across the wet FGD system, but it is small. It should be noted that the wet FGD system at Site S5 is a magnesium-enhanced lime system.

Table 4-3
Average and Percentage of Total OH Mercury Results for S5

	Average, $\mu g/Nm^3$				Percentage of Total, %		
	Hg_p	Hg^{2+}	Hg^0	Hg_T	Hg_p	Hg^{2+}	Hg^0
Unit with SCR							
SCR Inlet	0.09	6.1	7.8	14.0	1	43	56
SCR Outlet	0.02	10.8	3.3	14.3	0	76	24
ESP Inlet	0.07	16.8	0.8	17.6	0	95	5
ESP Outlet	0.05	11.3	0.7	12.1	0	94	6
Stack	0.02	0.4	1.0	1.5	1	28	72
Average total mercury removal = 91%[a]							
Unit Without SCR							
ESP Inlet	0.05	10.8	2.7	13.5	0	80	20
ESP Outlet	0.01	7.9	4.7	12.6	0	63	37
Stack	0.00	0.5	6.1	6.6	0	8	92
Average total mercury removal = 51%[a]							

[a] Average Hg removal is defined: (ESP inlet - stack)/ESP inlet.

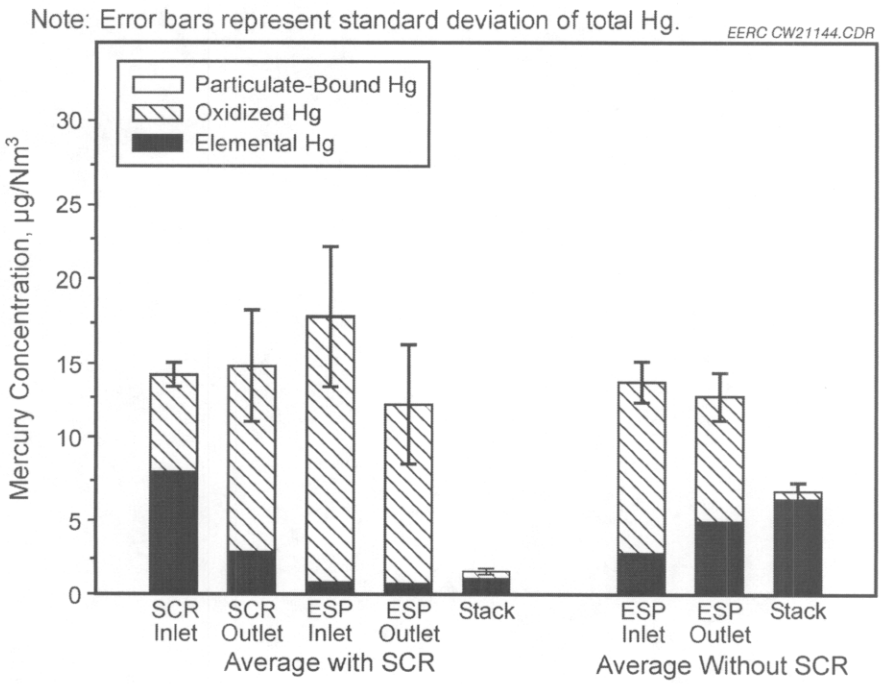

Figure 4-5
Comparison of Mercury Speciation Results with the SCR and Without an SCR at Site S5

Whether these mercury results would be consistent in the more common limestone forced-oxidation design is not known since the mechanism for reemission is not well understood. This is discussed in more detail in Section 6.4.

4.4.2 Hg SCEM Results

Hg SCEMs were operated at the ESP outlet location for both units tested. In an effort to gather longer-term variability data, Hg SCEMs were operated nearly continuously for 23 days. The Hg SCEM data for the entire test are shown in Figures 4-6 and 4-7.

Significant variability of total gas-phase Hg was observed at the ESP outlet location of both units. The statistical analysis for the Hg SCEM data is shown in Table 4-4. Correlation between the Hg SCEM data and the OH method at Site S5 is not very good. Using the OH method, the average total gas-phase Hg was 9.1 and 9.9 $\mu g/m^3$ with and without SCR operating (dry at actual O_2 levels). This compares to only 5.3 and 5.8 $\mu g/m^3$ as measured using the Hg SCEMs. There were significant problems associated with operating the Hg SCEMs at Site S5. It took a long time (over a week) to get the instruments operating, and once they began operating, there were substantial plugging problems of the sample lines and probe. In general, it is difficult to assess long-term variability of Hg concentration at S5. The abrupt shifts observed in the Hg SCEM data indicate that Hg concentrations were highly variable at S5. Complicating the Hg SCEM data interpretation further is a noticeable increase in Hg concentration following replacement of the probe or instrument filters.

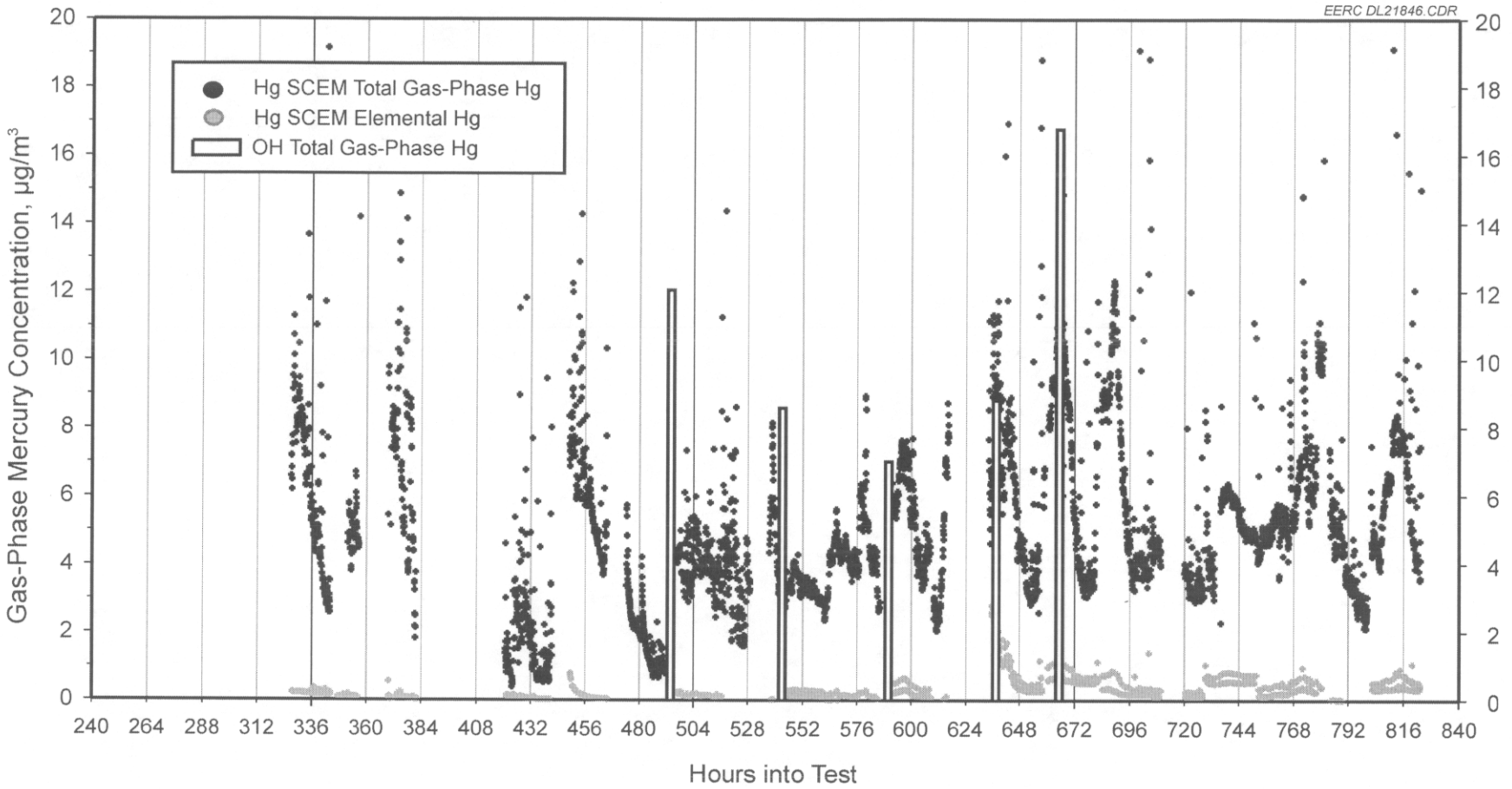

Figure 4-6
Hg SCEM Results for Site S5 for the Unit with an SCR

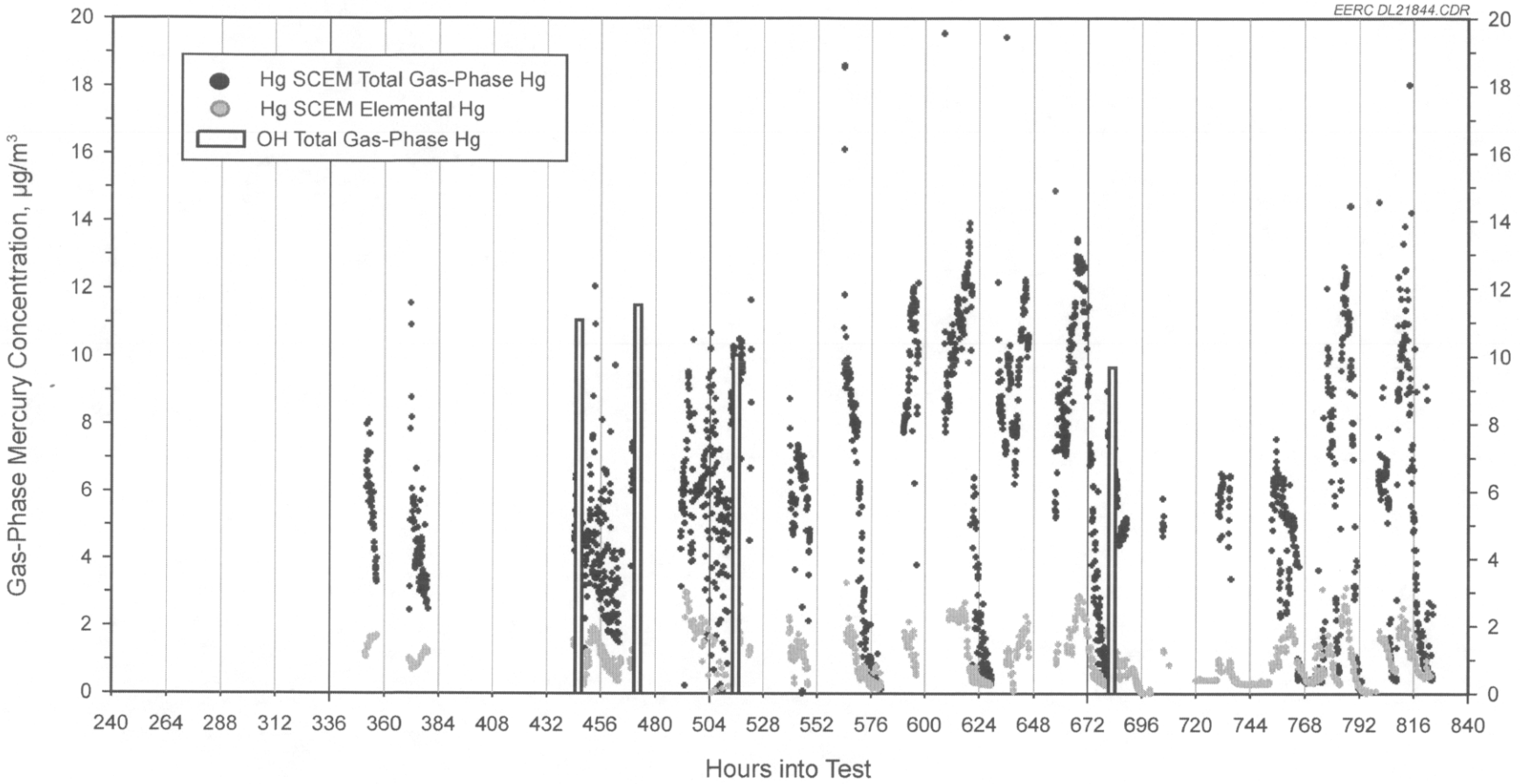

Figure 4-7
Hg SCEM Results for Site S5 for the Unit with No SCR

Table 4-4
Statistical Variation of the Mercury with and Without the SCR in Service Based on the Hg SCEM Data for Site S5

Mercury	Operation	Average, $\mu g/m^3$	Std. Dev., $\mu g/m^3$	Upper 90% CI, $\mu g/m^3$	Lower 90% CI, $\mu g/m^3$
Hg(total)	With SCR	5.3	3.9	11.6	0.0
Hg^0	With SCR	0.2	0.4	0.9	0.0
Hg(total)	SCR bypassed	5.8	3.9	12.2	0.0
Hg^0	SCR bypassed	0.8	0.7	1.5	0.0

4.4.3 Coal Analysis Results

Coal samples from S5 were analyzed for Hg and chloride. Both the coal Hg and chloride concentrations were very consistent. For six samples analyzed, the Hg and the chloride concentrations were 0.13 ± 0.013 and 472 ± 28 ppm, respectively. The analysis of the six coal samples is shown in Appendix B, Table B-7. Results of proximate and ultimate analyses for the coal are provided in Table 4-5.

Table 4-5
Coal Analysis for Site S5[a]

Date		7/28/2002	8/5/2002	8/15/2002
Mercury	ppm (dry)	0.14	0.12	0.15
Chlorine	ppm (dry)	430	500	480
Proximate Analysis				
Moisture	wt%	5.1	4.8	3.9
Volatile Matter	wt%	37.7	38.3	38.7
Fixed Carbon	wt%	44.4	45.3	45.3
Ash	wt%	12.7	11.6	12.1
Ultimate Analysis				
Hydrogen	wt%	5.3	5.3	5.3
Carbon	wt%	69.4	69.8	71.5
Nitrogen	wt%	1.4	1.4	1.4
Sulfur	wt%	3.6	3.5	3.8
Oxygen	wt%	7.6	8.4	5.8
Heating Value	Btu/lb	11,918	12,164	12,278
F_d Factor[b]	dscf/10^6 Btu	10,416	10,219	10,460

[a] Except where noted, all results are on an as-received basis.
[b] As defined in EPA Method 19.

4.4.4 ESP Ash Mercury Results

ESP hopper ash samples were collected daily throughout the test period from both test units. Ash analyses consisted of Hg and LOI determination and are presented in Table 4-6. In general, the Hg concentration in the ash was very low, <0.1 μg/g with or without SCR. The LOI for all samples analyzed was less than 7%. Based on these results, only a small amount of Hg was adsorbed by the ash and subsequently removed across the ESP. This is supported by OH results.

Table 4-6
Analysis of ESP Hopper Ash

	Hg, μg/g	No. of Samples	LOI, %	No. of Samples
Unit with SCR	0.094 ± 0.041	16	5.21 ± 1.27	5
Unit Without SCR	0.068 ±0.016	21	3.96 ± 0.87	6

4.4.5 NH_3 Slip and SO_3 Flue Gas Results

A summary of the NH_3 slip and SO_3 results is provided in Table 4-7. The NH_3 slip was less than 0.5 ppm for both samples, indicating an efficiently operating SCR. Based on the expected conversion of SO_2 to SO_3 that occurs across the SCR unit, it would be expected that the unit with SCR would have higher SO_3 concentrations than the unit without SCR. Comparing the results at the ESP sampling location, this is indeed the case. However, the results at the SCR outlet are much lower than seems reasonable and the ESP inlet SO_3 concentrations are actually higher. No clear cause has been identified that would explain these results.

Table 4-7
Flue Gas SO_3 and NH_3 Results for Site S5[a]

	SO_3, ppm		NH_3 Slip, ppm
Unit with SCR			
Date	SCR Outlet	ESP Inlet	SCR Outlet
8/18/2002	1.93		
8/18/2002		5.28	0.29
8/22/2002	1.71	16.03	0.34
8/22/2002	1.76	18.30	
Unit Without SCR			
Date	AH Inlet	ESP Inlet	
8/14/2002	10.61	9.92	
8/15/2002	5.06		
8/15/2002		5.13	

[a] Dry and 3% oxygen.

4.5 Mercury Mass Balance

Average Hg concentration in the coal and F_d factors (Table 4-5) were used to estimate the Hg emission rate at the various sample locations. For the Hg associated with the ESP hopper ash, the F_d factors were based on the dust-loading measurements as well as the F_d factor. The results are shown in Table 4-8.

Table 4-8
Average Mercury Emission Factors for Site S5

	lb Hg/10^{12} Btu				
	Coal	ESP Inlet	ESP Hopper Ash	ESP Outlet	Stack
Unit with SCR	10.8	13.4	0.2	9.2	1.1
Unit Without SCR	10.8	10.3	0.2	9.6	5.0

A Hg balance comparing the measured Hg in the flue gas at the ESP inlet location compared to the Hg generated by the coal is 124% with SCR and 95% for the test on the unit without SCR.

To determine the mass balance around the ESP the sum of the Hg associated with the ESP hopper ash plus the Hg in the flue gas at the ESP outlet must equal the Hg measured in the flue gas at the ESP inlet. The results of this balance for the units with and without SCR are 70%, and 95%. It should be noted that there was substantial variability in the Hg flue gas measurements. This is particularly true at the ESP inlet location where the standard deviation was 3.4 lb/10^{12} Btu for the unit with SCR and 2.9 lb/10^{12} Btu for the unit without SCR.

Unfortunately, the plant personnel did not provide FGD samples for analysis, and no plant data are available (gas flows, slurry feed rate, and blowdown) to estimate the Hg removal rates by the FGD. Therefore, it is not possible to do a Hg mass balance around the wet FGD system.

4.6 General Observations from S5

- There was an increase in Hg oxidation across the SCR catalyst. The percentage of Hg^{2+} in the flue gas increased from 43% to 76%. At the ESP inlet and outlet location, the percentage of Hg^{2+} was 95%.
- Comparing the Hg speciation results (at the ESP inlet location) with and without the SCR unit in service showed that the presence of SCR resulted in more Hg^{2+}: 80% without SCR and 95% with SCR. There was substantial variability at the ESP inlet locations for both units. If the ESP outlet data are used, the difference was 63% to 94%.
- The overall Hg removal was greater with an SCR: 51% for the unit tested without SCR and 91% when SCR was in service.
- There was an increase in Hg^0 across the wet FGD system for both units. For the unit without SCR, the Hg^0 concentration increased from 4.7 $\mu g/Nm^3$ at the FGD inlet to 6.1 $\mu g/Nm^3$ at the outlet. The increase was less for the unit with SCR: 0.7 to 1.0 $\mu g/Nm^3$.